Power-Feed System for the Newfoundland-Nova Scotia Link

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Design engineers now have available the results of many years of operating experience with submerged-repeater systems supplied from electronic, electromagnetic and rotary-machine power equipments. To meet the very high standards of reliability required for the transatlantic telephone system, a scheme has been evolved that is a combination of new developments and the best features of previous methods. Electronic-electromagnetic equipment forms the basis of an automatic no-break system requiring very little routine maintenance.

INTRODUCTION

The operating power for the submerged repeaters of the Clarenville-Sydney Mines link is derived from a constant current supplied over the central conductor from power equipments located at the two terminal stations. In order to protect the electron tubes in the repeaters the current must be closely maintained at the design value, irrespective of changes in the mains supply voltage or ground potential differences between the two ends of the link. Automatic tripping equipment must be provided to disconnect the cable supply should the current deviate beyond safe limits, but otherwise there must be a minimum of interruptions due to power-equipment and primary-source failures.

Earlier British Post Office schemes have been powered by electronically controlled units feeding from one end only.‡ Manual change-over to standby units has been provided at the end feeding power and at the distant end — a method which has satisfactorily met the economic requirements of short schemes.

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‡ Walker, D. C., and Thomas, J. F. P., The British Post Office Standard Submerged-Repeater System for Shallow-Water Cables (with special reference to the England-Netherlands System), *Proc. I.E.E.*, **101**, Part I, p. 190, Feb., 1954.

For the Clarenville-Sydney Mines link a new and more reliable design of equipment has been developed. An automatic no-break system provides an uninterrupted supply to repeaters unless equipments at both ends of the link simultaneously fail to deliver power.

The main improvement in the reliability of the equipment is the replacement of all high-power electron tubes by electromagnetic components. The automatic no-break system takes advantage of the fact that the rating of the repeater isolating capacitors has been chosen to permit single-end feeding. Normally the link is fed from both ends, but in the event of one equipment failing to deliver power the link is powered from the other end without interruption to the cable supply. If the failure is due to a power-equipment fault, double-end feeding can rapidly be re-established by manual switching to the standby. During an ac-supply failure, single-end feeding must be maintained until the supply is restored. In view of the very reliable no-break ac supply provided at both stations, the possibility of a simultaneous ac supply failure at both ends of the link is extremely remote.

The power equipments at each end of the link must be capable of supplying the whole of the power to the cable should one end fail, which requires that each should be capable of operating as a constant-current generator. If two constant-current generators are connected in series, unless precautions are taken, an unstable combination will result and the unit supplying the higher current will drive the other unit 'off load.' Manual adjustment could be provided to equalize the currents fed from the two ends, but a different solution has been developed in which one of the units is a constant-current master and controls the line current, while the other unit is a slave whose voltage/current characteristic in the normal operating range is such that its current is always equal to that of the master unit. If the slave unit fails, the master will take over the supply; if the master unit fails, the slave unit will take over the supply and automatically assume the role of a master unit. The first unit switched on to an unenergized link operates as a master generator and the other unit, on being switched on, automatically operates as a slave. Other than ensuring that the link is safe for energizing, there is no need for any cooperation between the two ends when putting the equipment into service.

DETAILS OF METHOD EMPLOYED

The Master-Slave System of Operations

The output-current/output-voltage characteristics for the equipments are shown in Fig. 1, and are the same for both regular and alternate

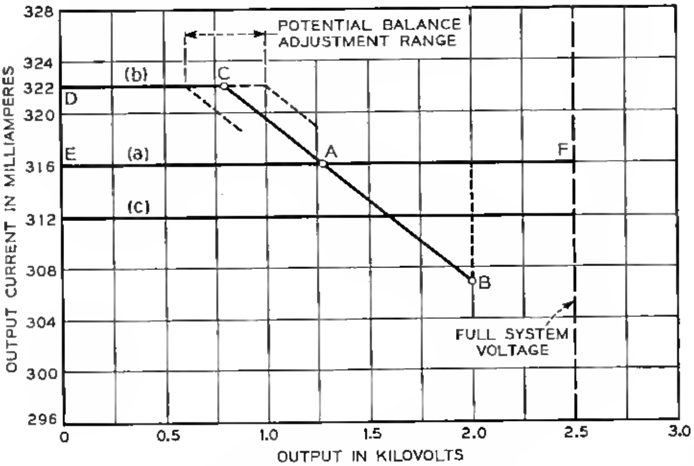

Fig. 1 — Output-current versus output-voltage characteristics. (*a*) Master. (*b*) Slave. (*c*) Master versus master shut-down.

equipments at both ends of the link. Any equipment can operate with any of the characteristics (*a*), (*b*) or (*c*).

Normally the choice between characteristics (*a*) and (*b*) is made automatically by the equipment. If the output voltage does not reach 80 per cent of the full link voltage (approximately 2 kv), the unit will have the slave characteristic (*b*) (DCAB). If the output voltage reaches or exceeds 2 kv, the unit automatically switches to the master characteristic (*a*) (EAF). Once having switched to the master characteristic the equipment does not automatically change back to the slave characteristic even if the output voltage falls below 2 kv.

When the link is energized, the first equipment switched to line will come on as a slave unit; its output voltage will then pass 2 kv and it will automatically be switched to the master characteristics and the complete link will be energized from one end. The second unit switched to line will come on as a slave unit, and having a higher output current, will drive down the output voltage of the master unit at the other end until the current of the slave unit has become equal to that of the master (DCA in Fig. 1). The output voltage of this equipment will not exceed 2 kv and it will not switch to master. The cross-over point of the two characteristics, A, will determine the potential fed from each end, and this can be adjusted as indicated by the dotted lines near C.

In an emergency, an equipment can be taken out of service by switching off the ac supply, and the links will then be powered from the dis-

tant end only. Sbould tbe master end be switcbed off, tbe distant slave unit will switch to master characteristic as soon as its output voltage exceeds 2 kv. This abrupt disconnection of one equipment causes unnecessary voltage surges on the cable, and when an equipment is removed for normal maintenance purposes the following procedure is adopted. The slave equipment is switcbed to the master cbaracteristic (an external key is provided for cbanging from master to slave or vice versa, but see the limitation described in tbe next paragraph). This leaves two master equipments feeding the cable, but any redistribution of voltage is slow since tbe currents are approximately equal. An external control (master/master shut-down), is then operated on the equipment to be taken out of service, changing its characteristic to that shown in Fig. 1(*c*). The output voltage of tbis unit will then be slowly reduced, and when it is zero the equipment can be switched off without causing surges on the cable.

The current deviations occurring over the slave characteristic (*c*) (from +2 per cent to −3 per cent) are the maximum permitted by the tube design engineers for the tubes in the submerged repeaters, and are permitted only for short periods. The circuit associated with the manual switching of tbe equipment to the slave characteristic is therefore made inoperative if the output voltage exceeds 2 kv, since in this range the slave characteristic is the extension of the line CAB on curve (*b*) and the current is outside the permitted range. The slave characteris-

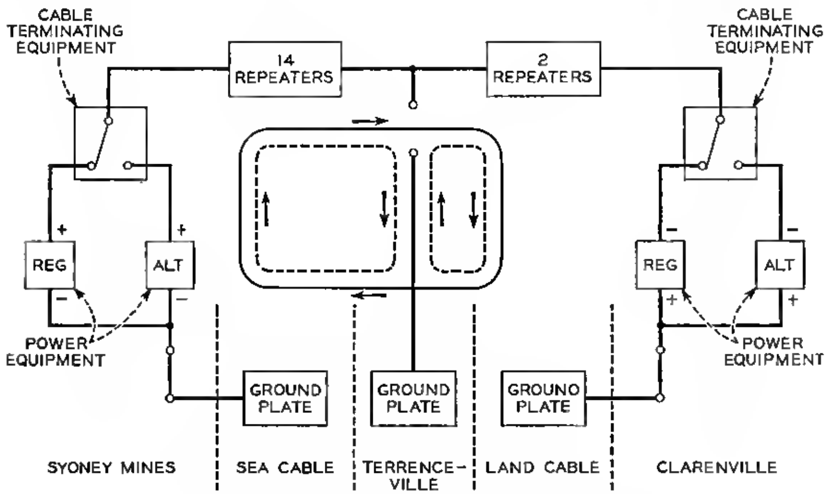

Fig. 2 — Current paths on Clarenville-Sydney Mines link.

tic over the range CAB is controlled by a voltage-sensitive circuit connected near the output of the equipment, and the stability of the characteristic against input voltage and component aging is the same as for the master characteristic. Changes in the distribution of the system potential due to supply variations and component aging are therefore small.

Overall Current and Voltage Distribution

Facilities have been provided at the junction of the land and sea cables (Terrenceville) to connect a power ground to the center conductor of the cable. Normally this ground will be disconnected, but during installation it enables the land and sea sections to be energized separately and may subsequently be of assistance in the localization of cable faults near Terrenceville.

The full line in Fig. 2 shows the current path with normal double-end feeding, while the broken lines show the current paths when a ground is connected at Terrenceville.

The full line (*d*) in Fig. 3 shows the voltage distribution along the link

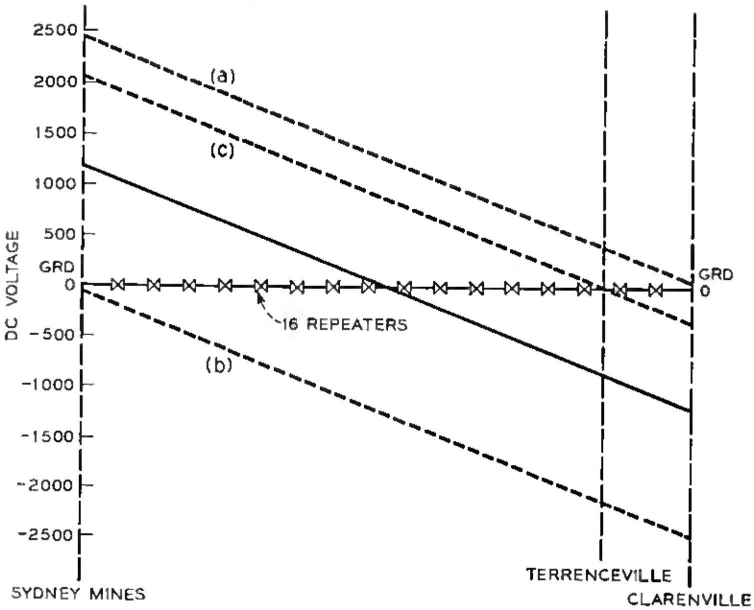

Fig. 3 — Potential distribution on Clarenville-Sydney Mines link. (*a*) Single-end feeding from Sydney Mines. (*b*) Single-end feeding from Clarenville. (*c*) Ground at Terrenceville; double-end feeding. (*d*) Normal operation; double-end feeding.

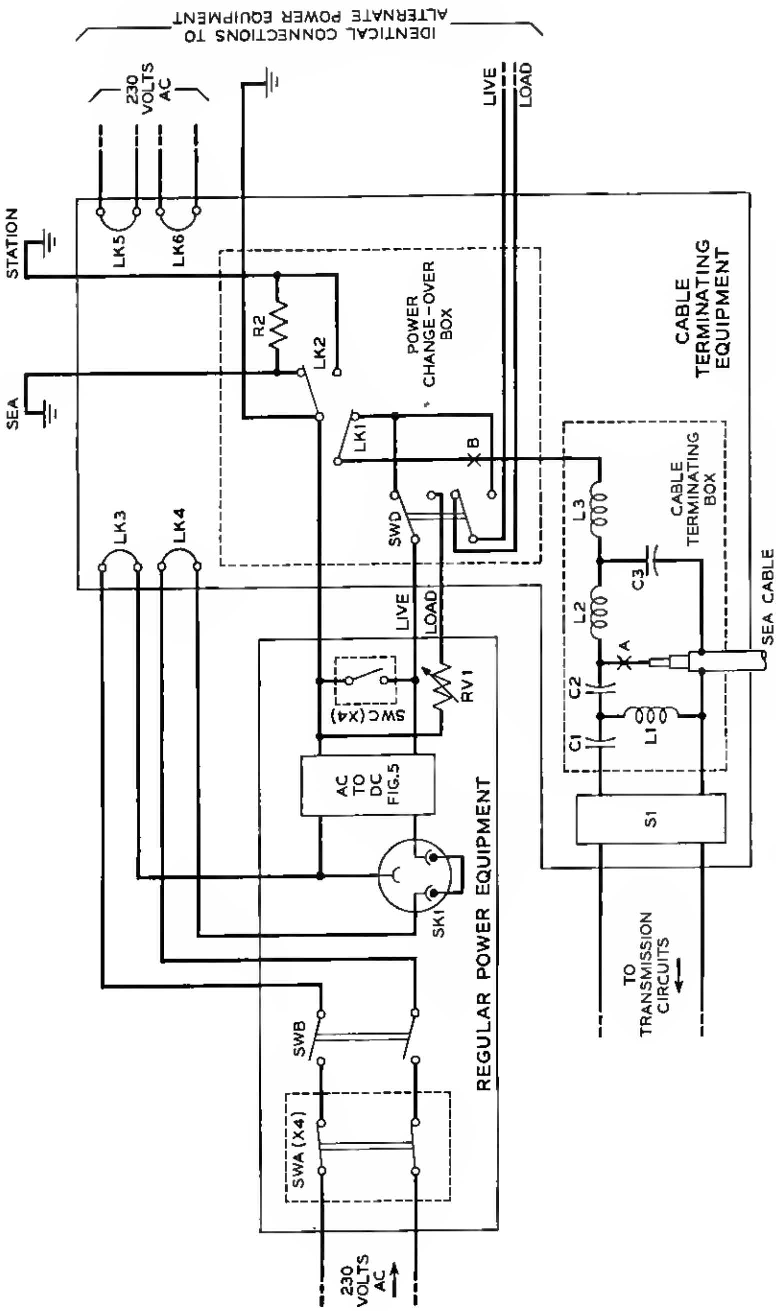

Fig. 4 — Cable terminating equipment and interconnections with power equipments.

with normal double-end feeding, the broken lines (*a*) and (*b*) show the distribution with single-end feeding from Sydney Mines and Clarenville respectively and the broken line (*c*) shows the distribution when a power ground is connected at Terrenceville.

DETAILS OF EQUIPMENTS

Connection of the Equipment to the Cable

Each station is provided with two power equipments and one cable-terminating equipment interconnected as shown in Fig. 4. When the live side of the output of the regular equipment is connected to the cable via SWD and the link LK1, the alternate equipment output is connected to its own dummy load (equivalent of RV1) and vice versa.

The grounded sides of the regular and alternate equipments are made common and then connected via a removable link, LK2, to the sea ground. A safety resistor R2 connects the sea ground to the station ground to restrict the rise in potential to 100 volts if the sea ground becomes disconnected. During maintenance on the sea-ground circuit the link LK2 can connect the power equipment ground to the station ground.

If, for maintenance purposes, it is necessary to feed from the distant end only, the link LK1 can connect the cable to the power-equipment ground and disconnect the live side of both power equipments from the line.

Safety Interlocks

Safety interlock circuits are installed to protect the maintenance staff if the equipments are used incorrectly and are not the normal methods employed for controlling the power supplies. With double-end feeding, dangerous voltages are generated at both ends of the system, and when access is gained to any point in the equipments personnel must be protected from the local and distant power sources.

To minimize interruptions to traffic, the units of the cable-terminating equipment have been grouped under three headings (see Fig. 4), namely

(*a*) Transmission equipment (S1) isolated from the dc cable supply: this includes cable simulators and monitoring facilities not associated with the power supplies.

(*b*) Equipment associated with the dc supply that can be made safe without interrupting traffic.

(*c*) Equipment that can be made safe only by interrupting traffic.

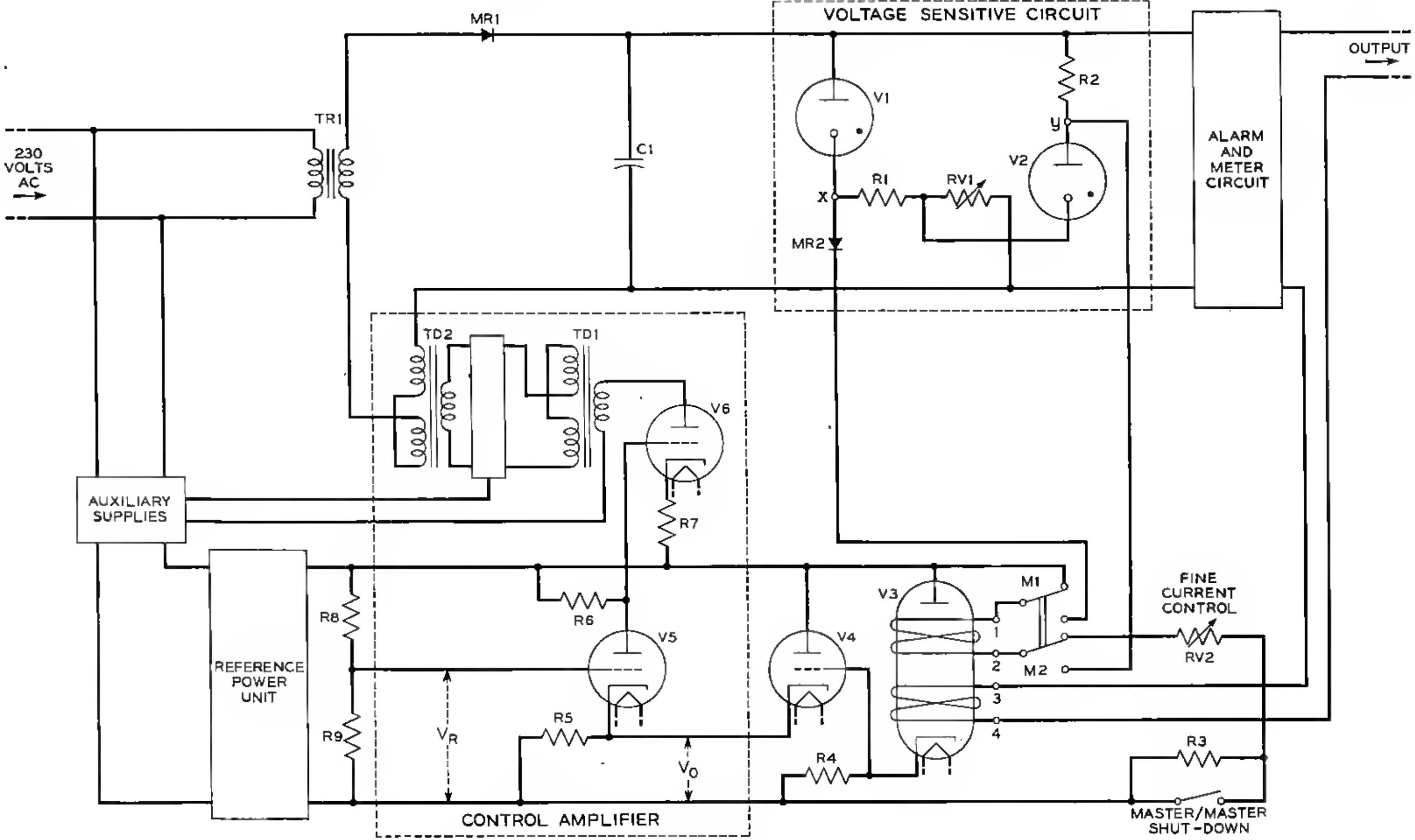

Fig. 5 — Simplified schematic of power-feeding equipment.

Group (*a*) is treated as normal terminal transmission equipment and is not interlocked. Groups (*b*) and (*c*), the power-change-over and cable-terminating boxes respectively, both require that the local power equipments are switched off before they can be made safe. The external panel covers over both boxes have links disconnecting the ac supplies to both of the local power equipments when the covers are removed (LK3–LK6). This will not interrupt traffic, since single-end feeding will continue from the distant station.

The doorknob switch of the power-change-over box automatically connects the live lead to ground (at the point B) when the door is opened. This will not interrupt traffic since the impedance of L2 is high at carrier frequencies. Changing over the power equipments and grounding arrangements can therefore be performed without interrupting traffic.

The doorknob switch of the cable-terminating box automatically connects the center conductor of the cable to ground (at the point A) when the door is opened. Traffic will therefore be interruped if maintenance work is necessary witbin this box.

Access is gained to a power equipment by opening one or more of four doors. Each of the doorknob switches disconnects the ac supply (SWA) and short-circuits the output of the equipment (SWC).

It will be appreciated that if the correct procedure is adopted the local power equipments will be switched off by SWB after the master/master shut-down procedure (described in section on *The Master-Slave Systems of Operations*) has been carried out and not by removing the panel covers or opening the doors.

Electrical Details of Power Equipment

Control Method.

Fig. 5 is a functional simplified circuit diagram in which TR1, MR1 and C1 represent a conventional unregulated power unit.

The control circuit compares a signal proportional to the output current, V_0, with a stable reference signal, V_R, the two signals being applied to the cathode and grid, respectively, of V5; the difference between them is amplified and used to adjuste the voltage fed to the rectifier circuit, MR1, to maintain the output current constant.

Ignoring at this stage the auxiliary coil 1-2 of the magnetically controlled diode V3, the output current flows through the coil 3-4 and controls the voltage across R4 and hence, via the cathode-follower V4, the potential V_0 on the cathode of V5. V_R is a function of the output of a conventional electronic constant-voltage power unit (reference power

unit) using a neon tube for its reference. The grid-cathode bias of V5 controls the secondary impedance of tbe transductor TD2 via the amplifier V5, V6, TD1. The gain of the control amplifier and the sign and magnitude of the normal impedance of the secondary of TD2 are arranged to give a fall of approximately 0.25 per cent in the current from full system load to short-circuit.

Two advantages are obtained by employing a magentically controlled diode for V3 instead of an electrostatically controlled tube. The control is directly proportional to the output current, and is not dependent upon the stability of a series resistor, while the control circuits are isolated from the output-circuit voltage, which simplifies maintenance of the more complex parts of the equipment.

Current Characteristics.

Without current flowing in the auxiliary coil 1-2 (on V3 in Fig. 5) the equipment has a normal constant-current characteristic, the value of which, 322 ma, is preset by adjusting the mechanical position of the coil assembly along the main axis of V3.

Two neon tubes and two resistors form the bridge V1, V2, R1 and R2, which is balanced when the voltage drop across R1 and R2 equals the constant voltage across V2 and V1, the output voltage at which this occurs being adjusted by RV1. At voltages below balance, current tries to flow from y to x and at voltages above balance it flows from x to y. The balance voltage corresponds to the voltage at which the slave-unit characteristic changes slope (C in Fig. 1). For voltages below balance the rectifier MR2 prevents current from flowing in the winding 1-2 (on V3), and in this range the constant current of 322 ma is maintained (see DC, Fig. 1). For voltages above balance, current flows in the winding 1-2 and progressively decreases the output current (CAB, Fig. 1). At 80 per cent of the full link voltage, the contacts of relay M are operated and disconnect the auxiliary coil 1-2 from the voltage-sensitive bridge and connect it across the reference supply. The current through 1-2 is then set by the fine current control (RV2) to make the output current the required 316 ma. As previously stated, relay M does not automatically switch back when the output voltage drops below 80 per cent of full link voltage; the current characteristic of a master unit is EAF in Fig. 1.

The master/master shut-down characteristic [Fig. 1, curve (*c*)] is obtained by short-circuiting R3, which causes the constant current to fall to 312 ma. Adjusting RV2 would be equally effective, but short-circuiting R3 does not permanently disturb the normal current settiug.

Alarms.

The equipment trips and gives both aural and visual alarms for +20 per cent current, +20 per cent full link voltage and for the failure of certain auxiliary supplies that would damage the equipment.

Aural and visual alarms are provided for ±1 per cent current and ±3 per cent voltage and for equipment changes from slave to master characteristic or vice versa. Visual indication is given if the ac supply fails.

Reliability.

Where possible, only components of proven integrity have been used. High-power thermionic tubes have been excluded and the tube types employed have been specially selected for long life. Electrolytic capacitors have been excluded from all except one position, and in this case the component has been divided into six units in parallel, the failure of all but one of these units causing only a slight increase in the output ripple.

Particular attention has been given to the continuity of the output circuit. A failure of a power equipment for any reason other than an open-circuit in the output will not interrupt traffic, the link changing to single-end feeding from the far end. A disconnection anywhere in the dc feed path will disconnect all power from the line. Relatively short-lived components in this part of the circuit have either been duplicated in parallel or shunted by resistors capable of carrying the full line current.

Other facilities.

Each equipment has facilities for checking its overall performance. A variable-ratio transformer can be introduced at SK1 (Fig. 4) and with the 4-position dummy load referred to earlier, the regulation against alternating input voltage and output load can be measured.

Provision is made for checking all the alarms, aud the current can be measured at strategic points in the control circuit either when the equipment is normal or with the loop feedback disconnected.

Separate large-size meters are provided for measuring the output voltage and current to an accuracy of ±1 per cent. A more accurate measurement of current is obtained from potentiometric measurements made across a standard resistor connected in series with the output.

Electrical Details of Cable-Terminating Equipment

The majority of the electrical features of the cable-terminating equipment have already been considered.

Within the cable-terminating box (Fig. 4) are the power-separating filters; the high-pass filters C1, C2 and L1 passing the carrier frequencies and the low-pass filter L2 passing the direct current. The transmission equipment represented by the block S1 is for convenience mounted in the cable-terminating cubicle. The extra low-pass filter L3, C3 can be specially designed to prevent signals that are peculiar to the site (local radio stations, etc.), which are picked up in the power equipment, from being fed to the transmission circuits.

Metering facilities (not shown in Fig. 4) are provided to check the continuity of the sea-ground circuit. A separate insulated wire is connected to the sea-ground plate and the continuity is checked by measuring the voltage drop along the ground cable. Aural and visual alarms are given if the sea ground becomes disconnected.

Current and Voltage Recorders

Current and voltage recorders are provided for both the regular and the alternate equipments, the values being measured at the points where the outputs of the power equipments enter the cable-terminating equipment.

A magnetic-amplifier unit drives the current recorder, the scale deflection being from -5 per cent to $+5$ per cent of the normal line current. The voltage recorder is connected across the ground end of a resistance potentiometer, the full-scale deflection being 3 kv.

The magnetic amplifier and potentiometer units are mounted in the cable-terminating equipment, but the four recorders and their associated supplies and alarms are mounted on a separate rack.

Mechanical Details

Fig. 6 shows two power equipments and a cable-terminating equipment as installed at each terminal station. The same cubicle frameworks are used for power and cable-terminating equipments, the power equipment consisting of two cubicles bolted side by side and fitted with doors at the front and back.

The top of the cable-terminating cubicle contains the power-changeover box, the center contains the cable-terminating box, while the transmission and ground-cable test circuits are located near the bottom. The

Fig. 6 — Power and cable-terminating equipments as installed at each terminal station.

main cable enters the bay at the top and passes behind the power-changeover box into the cable-terminating box. Access to the recorder units and cable simulators is from the rear.

Fig. 7 shows the front of one power equipment with the doors open. The left-hand cubicle contains the main h.v. transformer, the electronic and magnetic parts of the control circuits, the reference power unit and the auxiliary supplies. The other cubicle contains the main rectifier and smoothing circuits, and the associated meter and alarm circuits.

PERFORMANCE

Six power equipments and four cable-terminating equipments were manufactured for the link. Of these, four power equipments and two cable-terminating equipments were provided for the terminal stations and the remainder were for use on H.M.T.S. *Monarch* during the cable laying and subsequently as off-station and training spares.

After individual testing, the power equipments were checked in pairs energizing a 16-section artificial cable constructed to simulate the Clarenville-Sydney Mines link. These tests were kept running for approximately two weeks on each equipment, and the line current was monitored with

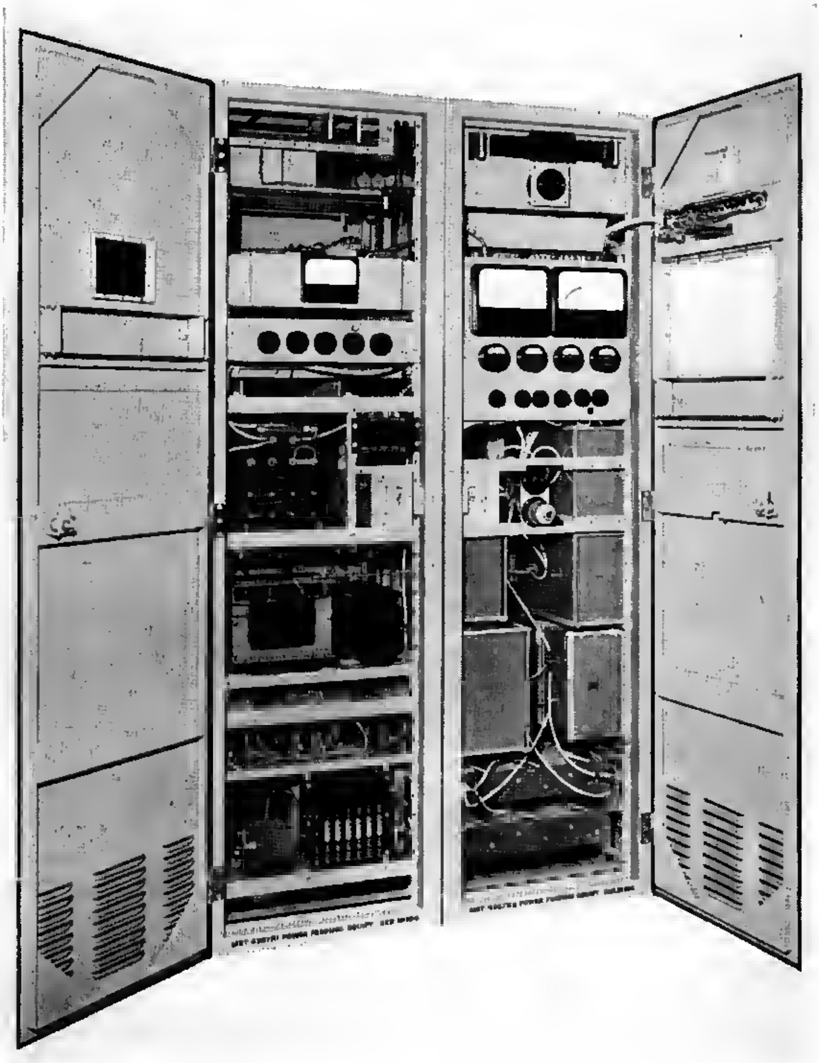

Fig. 7 — Power equipment.

expanded-scale current recorders (from -1 per cent to $+1$ per cent of the normal current).

The equipments were completed at the beginning of 1956, and have given satisfactory service both at the terminal stations and on board H.M.T.S. *Monarch.* From March to June, 1956, all four units at the

terminal stations were operating into their dummy loads and daily current and voltage readings were well within the required specifications. Since the laying of the sea section the equipments have satisfactorily operated the completed link. When the link is in service the working equipment at each end will be changed at 6-monthly periods and the change-over time will be staggered by three months each end. The equipment coming out of service will be immediately routine checked and adjusted if necessary.

The tests since installation confirm the laboratory and factory results that the regulation is better than ± 1 ma for any alternating input voltage from 195–265 volts in the frequency range 40–70 cycles for output voltages of 0 to 3 kv. The relatively long correction period of the magnetic-amplifier control circuit (about 0.5 sec) is satisfactory with the type of no-break supply installed at the stations.

Another useful by-product of double-end feeding is that, when there is a shunt fault on the system, the voltages supplied from the two terminal stations give an indication of the fault position. Many factors will control the accuracy of the location, e.g. magnitude and position of the fault, and how nearly the currents fed from the two ends are equal. Calculations, confirmed by tests made with shunt faults introduced at Terrenceville, show that any continuous shunt fault that will affect transmission (to the extent of operating the 1 db pilot alarms) will be detected to an accuracy of ± 1 per cent. The limit is set by the accuracy with which the link voltage distribution can be measured.

CONCLUSIONS

The power-feeding system described is suitable for submerged-repeater schemes that can, in an emergency, be temporarily powered from one end only. For locations within reasonable reach of a central catastrophe-spare store the equipment should be sufficiently reliable not to need duplication at both terminal stations. For future schemes this will provide a method which is economically attractive compared with the present single-ended methods and which offers numerous electrical advantages.

The routine maintenance required on the power equipment could be further reduced if the few remaining electron tubes were replaced by electromagnetic components. On schemes where short interruptions to traffic do not involve a relatively high loss of revenue it would then be unnecessary for the local staff to maintain the high-voltage equipment and the expensive no-break ac supplies could be abandoned. The latter

depends upon the probability of the primary sources at the terminal stations failing simultaneously.

ACKNOWLEDGMENTS.

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